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Thermal performance analysis on different types of glazing of public rental housing in Hong Kong

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Abstract

Thermal properties of glazing facades and windows system may affect the solar heat gain through its heat transfer area to an enclosed built environment, eventually affects the electricity consumption of air-conditioning system. Advanced glazing technologies offer a lower solar heat gain. This research project examines the relationship between the types of glazing, orientation and window-to-wall ratio (WWR) against the solar heat gain through the fenestration and annual electricity end uses for a window-typed air-conditioning system, by means of building energy simulation software, EnergyPlus. Reduction of electricity end uses and windows heat addition for the same windows configuration with different advanced glazing ranges are 13.8% and 69.1% respectively, in Hong Kong. The relationship among different construction configuration and climate is investigated. The optimum choice of glazing for minimizing the heat gain and maximizing the visual transmissibility is also suggested in accordance to the simulation results.

Keywords: Glazing, Heat gain, Electricity end uses, Window-to-wall ratio, Optimum configuration

1. Introduction

Facade with glazing material generally exists in commercial and residential building to offer external view and ventilation to occupants. There is a need for choosing an appropriate glazing for energy saving. Window heat

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addition constitutes the major sector of building envelope heat gain [1] in which the solar heat gain through window is the dominant component over others [2]. In Hong Kong, around 30% of total electricity consumption is used for space conditioning in residential and commercial building [3]. Therefore, reducing solar heat gain from a well-chosen glazing or windows may reduce the cooling load of an indoor environment and hence reducing electricity end uses with adaptation of day-lighting. Apart from the traditional single-glazed windows or façade, various combination of the following configuration are available in commercial market worldwide.

Considering single-glazed façade as a baseline, the energy consumption savings for double-skin-façade is possibly up to 9.18% in Building 5, Hong Kong Science Park [4]. The U value of low-e panel can be reduced by 59 to 64% comparing with single-glazed type [5]. Among different options of gas-filling, the magnitude of U-value in increasing order is as Krypton, Argon and Air [6]. The result of simulation performed in a Greece's office building shows that grey tinted glass can balance the annual energy consumption and solar heat gain [7]. Photovoltaic-double-skin-façade is examined to be suit-able for application in Hong Kong with proven energy saving potential [8]. For low-e coating, re-radiation resulting from heat absorption of the glass can be avoided while spectrally selecting a portion of visible light for transmission [9]. The Annual energy consumption of small-scale building significantly increases with the increased window size regardless of its position [10].

2. Methods

2.1. Description of Energy Plus

With due consideration of complicated mathematical modelling for heat and mass transfer, and performance of commercially available product, "EnergyPlus" (EP) is adopted for building energy simulation. It is developed by the Department of Energy of United States and it complies with the Heat Balance Method developed by ASHRAE. The Heat Balance Method, in Figure 1, include for four different processes, outdoor-face heat balance, wall conduction process, indoor-face heat balance and air heat balance. The energy balance for this method not only consider the 3 modes of heat transfer, but also consider the heat transfer between the adjacent surface and a zone. Output data for a specific parameter, for instance, cooling load and temperature, can be exported as a spreadsheet, consisting the data over a specified period.

2.2. Description of simulation model and case study

The building layout and construction details for the simulation model refer Living/Dining/Bedroom in a modular flat in Block 5 of Lei Yue Mun Estate of Hong Kong Housing Authority (HKHA). Fig.1 shows the Left Flat, consisting of a front window and a slide window. Right Flat, symmetrically the same as Left Flat, is also considered in the simulation. The flat is approximated as a rectangular compartment (2.35 x 0.55 x 2.6 m), where the entire south facing wall and part of the east facing wall for left flat are under sunlight. The rest of the surface are assumed to be adiabatic surface since the air conditioner may be not intended to provide cooling for the bathroom and kitchen, where the generation of water vapor may exist.

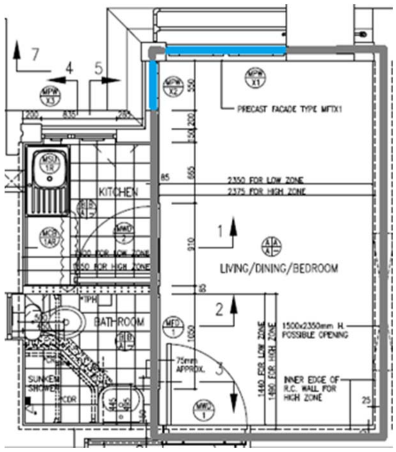

Fig.1 . Typical Floor Plan for Modular Flat in Block 5 of Lei Yue Mun Estate, HKHA

2.3. Parameters for simulation

To investigate the change of the output results with respect to the change of one construction related parameters, the following characteristics of occupancy usage are maintained constant. It is assumed 4 persons live in the flat with normal activity level. Lighting, small power load and air-conditioning are operated under the same schedule with design condition from Table 1. The thermal properties of glazing material (#1-#7) is based on the software "Berkeley Lab Window v7.4.8" [11], which provide the thermal properties of standardized glazing, certified by National Fenestration Rating Council (NFRC), as shown in Table 2. The selected glazing in NFRC are either single layer or double layer glazing systems since the economical and architectural consideration in public housing generally does not allow the utilisation of high-cost technologies, such as ventilated façade and photo-voltaic. Thermal properties of two glazing from HKHA document, are presented in the last two row (#8-#9) of Table 2. For the floor, opaque wall and roof, the physical configuration and thermal properties are referenced to the document in HKHA and code of practice from the Building Department of HKSAR as tabulated in Table 3 [12].

Table 1 Air-conditioning System Load Design Conditions

Item	Design Condition
Outdoor Condition (HKSAR, 2015)	Summer: Dry bulb temperature of 35℃ with wet bulb temperature of 29℃ Winter: Dry bulb temperature of 7℃
Indoor Condition	Dry bulb temperature of 24℃ with Relative humidity of 50%
Small Power Load	1000W
Lighting Load	8 W/m^2

Table 2 Thermal Properties of Glazing

#	Glazing Type	Overall Thickness [mm]	U-Value [W/m^2. ^{o}K]	SHGC	T_{vis}
1	Single Clear	3.05	5.681	0.681	0.899
2	Double Clear Air	23.43	2.842	0.704	0.786
3	Double Low-e Air	21.60	1.608	0.431	0.639
4	Double Clear with Argon	18.80	2.719	0.764	0.814
5	Double High Solar Gain Low-e	25.93	1.695	0.686	0.741
6	Double Low-e Vacuum	8.06	0.672	0.354	0.691
7	Double Sage Green	24.45	1.834	0.273	0.496
8	Tinted Glass (HKHA)	6.00	0.67	0.58	0.74
9	Clear Float Glass (HKHA)	6.00	0.97	0.84	0.89

Table 3 Thermal Properties of Building Materials

Components of Finishes	Thickness [mm]	Density [kg/m^3]	Thermal Conductivity (k) [W/m °C]
Floor			
• Mosaic Floor Tile	7	2500	1.50
• Cement Sand Screed	40	1860	0.72
• Concrete Wall	160	2400	2.16
Wall (Living/Dining, Bedroom)			
• Cement Sand Rendering	30	1860	0.72
• Concrete Wall	200	2400	2.16
Ceiling			
• Concrete Wall	200	2400	2.16

* Concrete Wall is considered as "Normal Weight Aggregate" option from (HKSAR, 1995)

The location and design day are imported from EP official website. Besides the Hong Kong climate, Beijing and Singapore are Asian countries, geographically and meteorology different, where both require the operation of an air conditioning system in the summer. The climate of these two countries are considered in the simulation with the same input parameters for comparison purpose. Table 4 summarizes the geographical data of the above 3 countries.

Table 4 Summary of Geographical Data

Country	Latitude [°]	Longitude [°]	Koppen-Geiger climate classification
Hong Kong	22.32	114.17	Cwa (Temperate-Dry Winter-Hot Summer)
Beijing	39.93	116.28	Dwa (Cold-Dry Winter-Hot Summer)
Singapore	1.37	103.98	Tropical-Rainforest

The geometry of the space for simulation is based on the architectural layout (Fig.2) of a modular flat of the HKHA. Apart from the flat setting from the layout, the size of the windows is varied, illustrated in Figure 2, such that 11 Window-to-Wall Ratio (WWR), in the step of 10% (i.e. 0-100%), is reached. Each of the above case is used to simulate with respect to 8 orientations including North (N), North-East (NE), East (E), South-East (SE), South (S), South-West (SW), West (W) and North-West (NW). Angle to Ture North Axis is an input parameter for EP Input Data File. 0o corresponds to the South (S) orientations and every increment of 45o would rotate the whole zone in clock-wise direction, such that the simulation result at different orientations is obtained. For the ease of data presentation, surface azimuth angle is used for the presentation of simulation results.

Fig.3 illustrates the independent variables of the overall simulation setting. The output of EP includes 5184 sets (i.e. 3 countries, 2 flats, 8 orientations, 12 WWR and 9 glazing) of annual window heat addition in GJ and annual electricity end uses of the air-conditioning system in GJ. The average window heat addition in W/m^2 is further determined by dividing the annual window heat addition by the glazing area and the time of year.

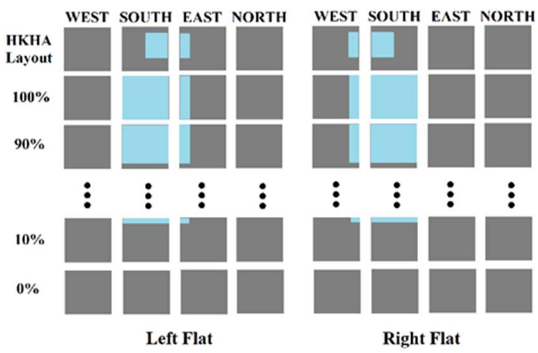

Fig.2 Wall Configuration under different WWR.

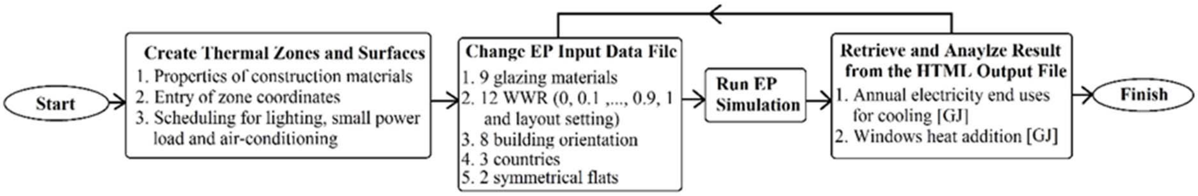

Fig.3 Flow Chart for EnergyPlus Simulation.

3. Results

The simulations were run in annual basis with the input data stated in section 2. The average window heat addition in W/m^2 indicate how much thermal energy is transferred through the glazing per unit area throughout a year. The annual electricity end uses for cooling in GJ represents the electricity consumption for the window type air-conditioning unit.

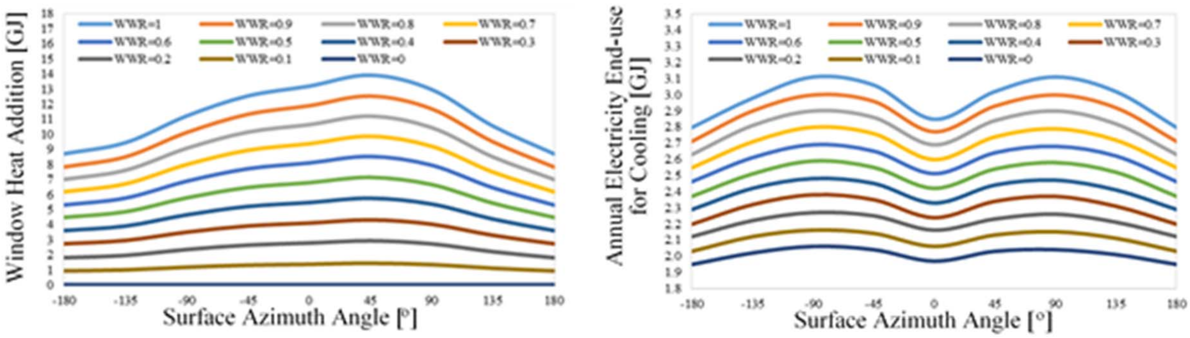

Fig.4 a Windows Heat Addition for Left Flat in Hong Kong (Left Figure), b Annual Electricity End Uses for Cooling for Left Flat in Hong Kong (Right Figure)

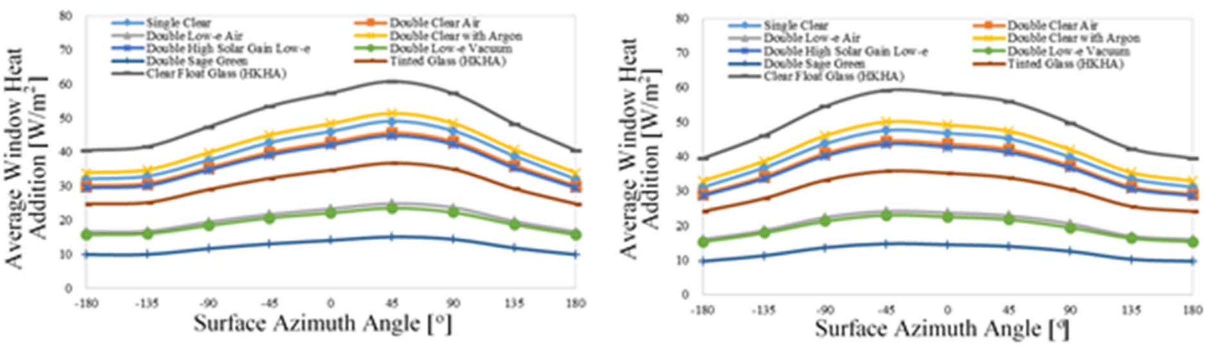

Fig.5 a. Average Window Heat Addition (HK Climate) Left Flat (Left Figure), b. Average Window Heat Addition (HK Climate) Right Flat (Right Figure).

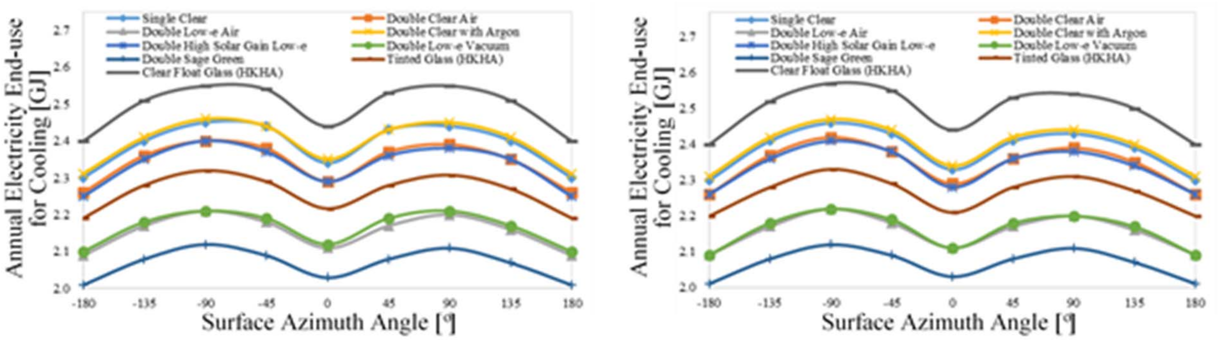

Fig.6 a. Annual Electricity End Uses for Cooling (HK Climate) Left Flat (Left Figure), b. Annual Electricity End Uses for Cooling (HK Climate) Right Flat (Right Figure)

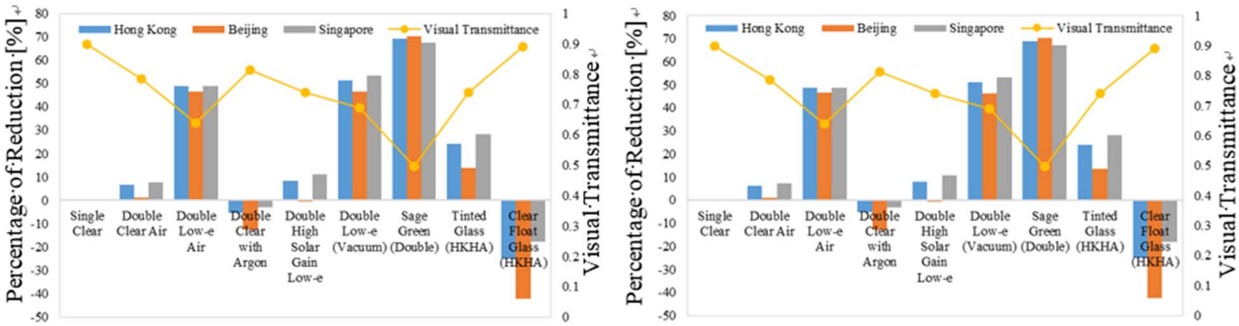

Fig.7 a. Percentage of Reduction in Average Window Heat Addition for Left Flat (Left Figure), b. Percentage of Reduction in Average Window Heat Addition for Right Flat (Right Figure)

Table 5 Range of Percentage change of Electricity End Uses for Cooling for WWR=0 and 1

	#1	#2	#3	#4	#5	#6	#7	#8	#9
Hong Kong	35.6	32.9	12.8	39.1	33.4	13.8	2.0	26.5	52.6
	29.2	26.7	9.6	32.1	27.2	10.7	-0.2	21.8	43.6
Beijing	98.0	104.9	60.3	121.9	113.6	69.8	31.6	103.6	170.8
	71.5	81.8	41.3	95.1	91.5	54.6	16.3	81.1	136.4
Singapore	21.9	42.0	18.3	49.0	42.2	18.7	6.7	33.6	63.2
	17.7	33.3	13.7	38.6	33.3	14.7	3.4	26.0	50.1

4. Discussion

4.1. Influence of the change of orientation, SHGC and WWR

The maximum and minimum of the windows heat addition occurs at the North and South West in Hong Kong. It could be attributed to the long duration of exposure to sunlight in a low incidence angle. Solar radiation comprises of direct, diffuse and reflected components, whereas the diffuse component depends on the angle of incidence. For East and West facing walls, they will be under exposure of sunlight with a lower incidence angle in the morning and afternoon respectively, which accumulate more heat than the wall facing other orientations. The heat transfer rate per unit glazing area is affected by SHGC, solar irradiance, U-value and the temperature difference between indoor and outdoor environment. The magnitude of SHGC may be the dominant factor of the solar heat gain. In Hong Kong, the maximum out-door dry bulb temperature in the summer is 35℃ and the indoor temperature should be equal or above 22℃ [13], which lead to a temperature difference up to 13℃. In contrast, depending on the location, the solar irradiance level could be larger than 1000W/m2 and below the limit from the solar constant 1367W/m2. Therefore, a small increment of SHGC may result in a significant raise in windows heat addition and the electricity end uses for cooling, irrespective of the U-value. Meanwhile, the amount of heat transfer is also varied by WWR, which is related to the physical construction of a windows and glazing façade.

$$\frac{q}{A} = \frac{q}{(A_{WWR=100\%})(WWR)} = (\tau + N_i\alpha)I_t + U(T_0 - T_i) = (SHGC)I_t + (U)\Delta t \quad (1)\ [14]$$

4.2. General relationship between electricity end uses for cooling and average windows heat addition

Simulation result shows that the variation of electricity end uses for cooling and average windows heat addition are almost in phase, in which the occurrence of maximum and minimum is consistent for all glazing type and orientation, in the same location. It is because the heat transfer through the building envelop, including window and wall may be dominant to others, contributing a large sector in the electricity end uses. However, the orientation of the occurrence of the peak electricity end uses and heat gain is slightly lagging to each other regardless of the material it uses. This is attributed from the thermal mass effect. “Windows Heat Addition” in EP solely considers the instantaneous heat gain and is not the same as cooling load. The building windows and walls absorb the heat energy in an earlier hour and releases it with a time lag, causing a higher heat transfer rate and electricity end uses.

4.3. Optimum choice for energy saving

Previous discussion arises the relationship between heat gain and WWR, where the lower WWR may lead to a lower heat gain. Therefore, a simple optimum WWR should not be concluded for all buildings. Instead, detailed simulation by computational fluid dynamics and on-site measurement may be an appropriate way to estimate a WWR for a specified premise. Among all 9 types of glazing and compared to single clear glazing, Double Sage Green could provide the most significant reduction in solar heat gain and electricity use, by approximately 69% and 16%, respectively, in the 3 examined countries. Concerning the need of both energy saving and visibility, Both Double low-e air and Double low-e vacuum yield a reduction in solar heat gain and electricity use by approximately 50% and 10%, respectively, whilst the visual transmittance could be up to 60%. North is the optimum orientation for energy saving for Hong Kong and Beijing. However, the optimum orientation for Singapore is South, due to different geographical parameters.

4.4. Unexpected circumstance and Possible application of the simulation result

Double clear with argon glazing is filled with argon in the air gap leading to a lower thermal transmittance than the double clear with air glazing. From figure 5 and 6, the percentage of reduction of heat gain and electricity use for double clear with argon (#4) is lower than the double clear with air (#2). It is because of the SHGC of the #4 is slightly greater than #2, leading to a major change in the solar heat gain despite the U-value and thickness of #4 is slightly lower than that of #2.

Although the simulation result is based on a flat in the public rental housing in Hong Kong, the simulation result provides construction professionals a “Rule-of-thumb”, in which the variation among window heat addition, electricity end uses for cooling, building orientation, WWR and glazing type are included. Since maximum solar heat gain occur when the orientation is South-West, in Hong Kong and Beijing; and North-East, in Singapore, the WWR of the building envelope could be reduced for the reduction of solar heat gain or replaced with green-wall, such that the electricity end use for cooling could be reduced.

5. Conclusions

Reduction of electricity end uses and windows heat addition for the same windows configuration with different advanced glazing ranges are 13.8% and 69.1% respectively, in Hong Kong. The configurations that leading to the occurrence of extreme heat gain and electricity use are also discussed for the Beijing and Singapore climate, with the same simulation parameters used for Hong Kong. Although admitting excessive solar heat gain of a building may be discouraged since a positive correlation between windows heat addition and electricity end uses for cooling is demonstrated, overheating problem related to sunlit area may be mitigated through reducing the glazing area and the utilization of tinted glazing or double glazing.

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